(12) UK Patent Application (19) GB (11) 2 202 001 (13) A

(43) Application published 14 Sep 1988

(21) Application No 8705836

(22) Date of filing 12 Mar 1987

(71) Applicant
Ford Motor Company Limited

(Incorporated in United Kingdom)

Eagle Way, Brentwood, Essex

(72) Inventor
Thomas Tsoi-Hei Ma

(74) Agent and/or Address for Service
A Messulam & Co
24 Broadway, Leigh on Sea, Essex

(51) INT CL⁴
F02D 13/02 F02B 29/08

(52) Domestic classification (Edition J):
F1B 1G1P B130 B212 B228 BE

(56) Documents cited
None

(58) Field of search
F1B
Selected US specifications from IPC sub-classes
F01L F02B F02D

(54) I.C. engine inlet valve timing control

(57) Fixed profile inlet cams 22*a* to *d* have a long event duration (e.g. 300°) and under low load conditions achieve a small exhaust overlap and a closing time sufficiently delayed to reduce the intake charge into the cylinder by permitting partial expulsion of the charge during the early part of the compression stroke thereby limiting the maximum output of the engine under full throttle. A first mechanism (layshaft 16) is provided for phase shifting the inlet cams to advance the closing and opening times by equal amounts so as to provide a first increase in maximum power output by increasing the valve overlap and increasing the trapped charge, and a second mechanism (harmonic drive 20) is provided for varying the event duration so as to provide a further increase in maximum power output by further advancing the closing times of the inlet valves to increase the intake charge without a corresponding advance in the opening times of the valves.

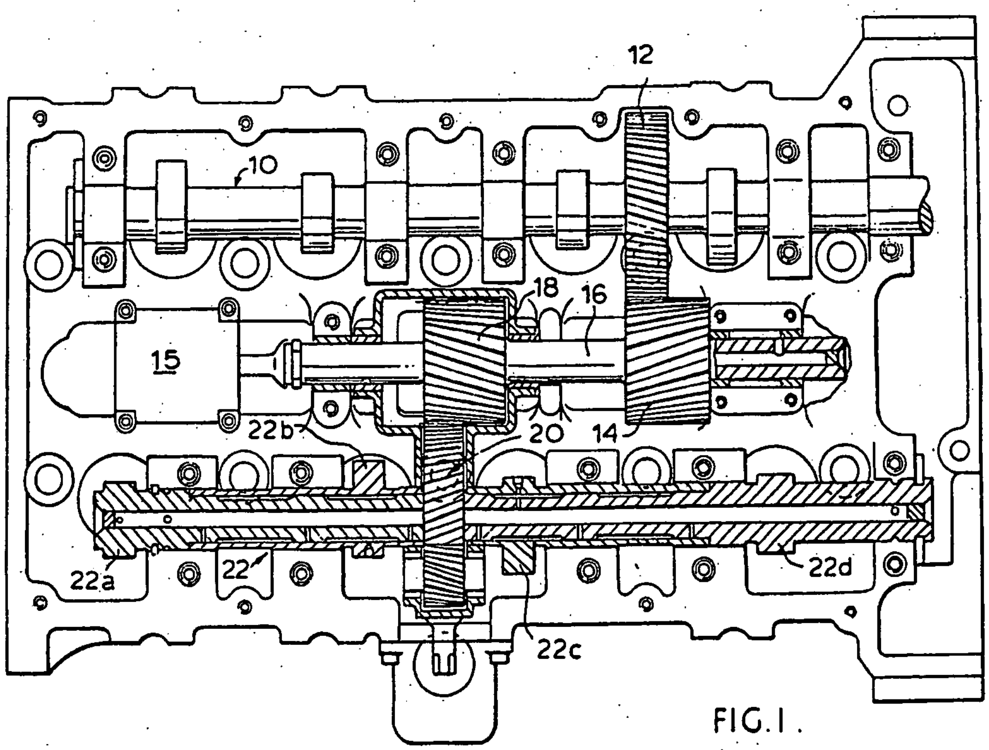

FIG.1.

The drawing(s) originally filed was (were) informal and the print here reproduced is taken from a later filed formal copy.

GB 2 202 001 A

2202001

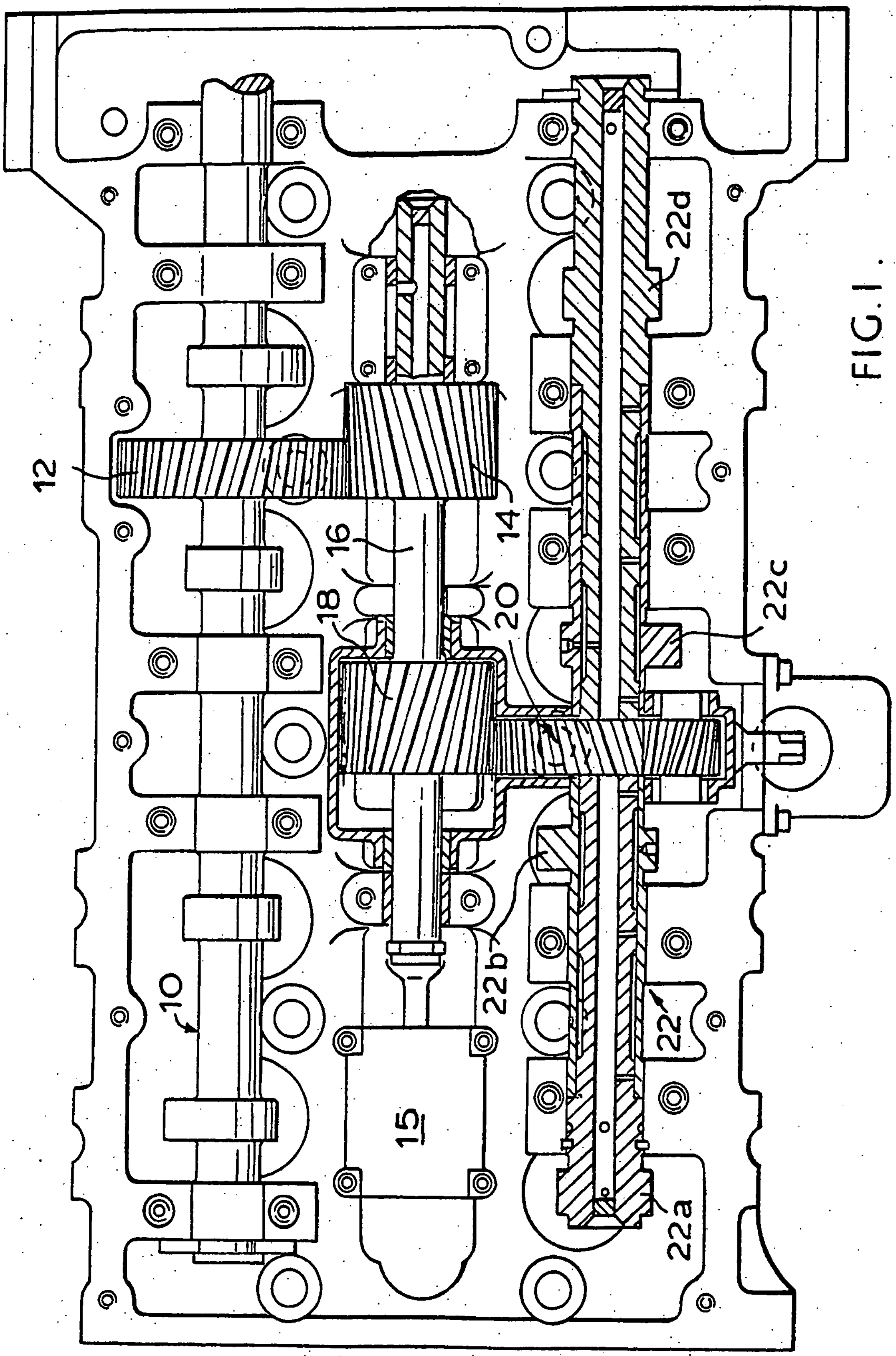

FIG. I.

2202001

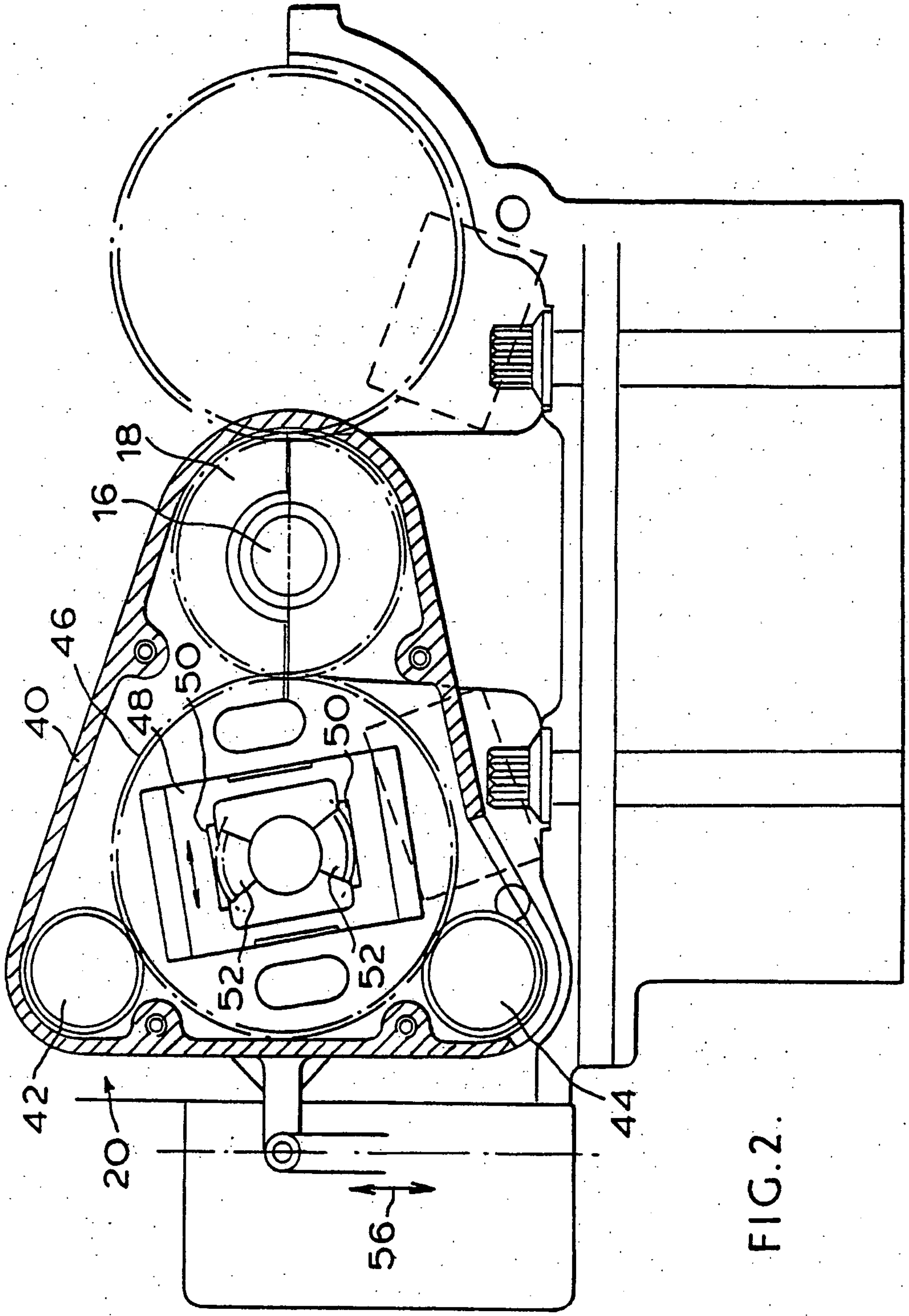

FIG.2.

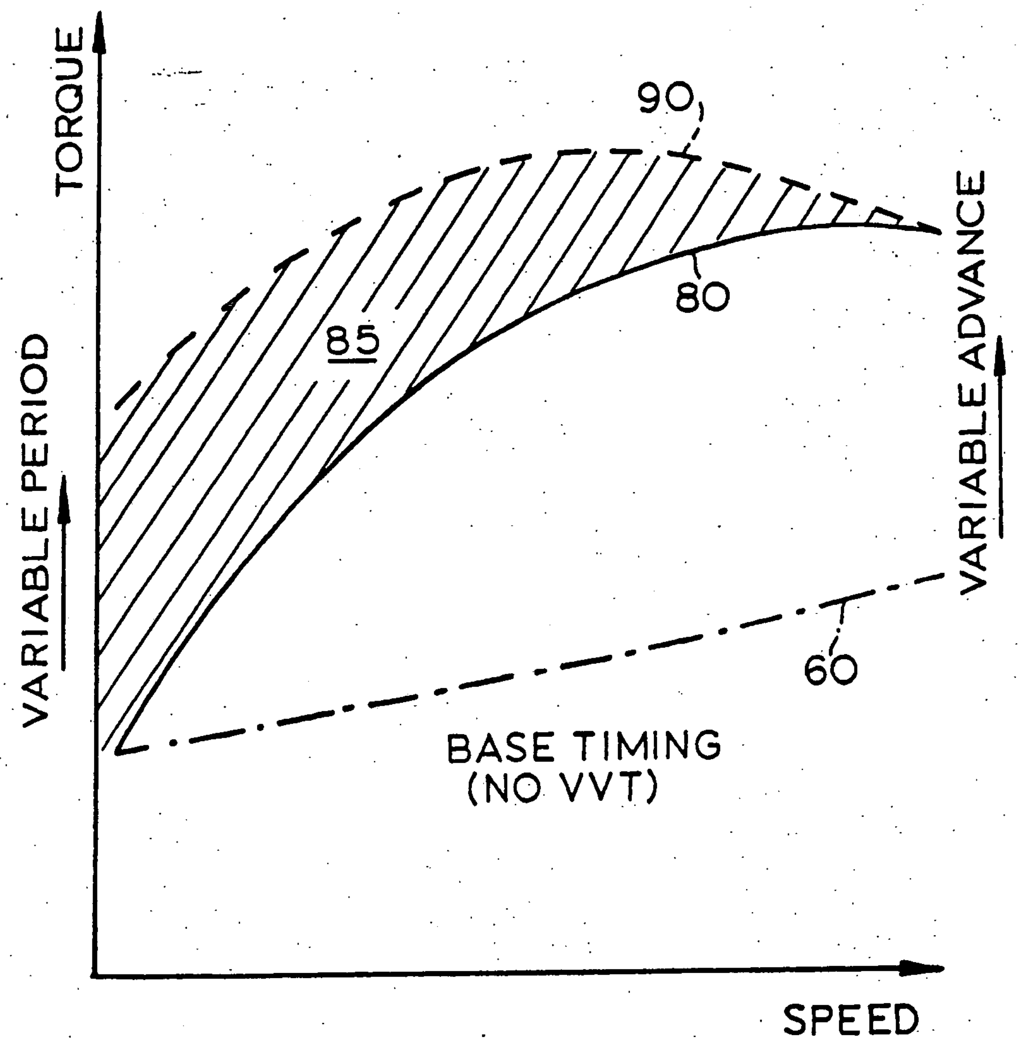
TORQUE
90
85
80
VARIABLE PERIOD
VARIABLE ADVANCE
60
BASE TIMING
(NO VVT)
SPEED

FIG.3.

INTERNAL COMBUSTION ENGINE 2202001

The present invention is concerned with the control of internal combustion engines having variable valve timing (VVT).

Hitherto, VVT has been proposed to compensate for bottom end performance of an engine whose valve timing is designed for high speed performance. The problem with this is that VVT usually creates increased friction. The friction is most noticeable at the lowest engine speed and load and since VVT is in use mostly under these conditions, this tends to counteract some of the potential benefit to be achieved by it.

VVT has also been proposed to avoid throttling and pumping losses at part load. Here the cams are designed for high performance and VVT is used to de-rate the breathing to reduce power output with less resorting to throttling.

The present invention provides an internal combustion engine which comprises a fixed profile inlet cam having a long event duration and phased under low load conditions to achieve a small exhaust overlap and a closing time sufficiently delayed to reduce the intake charge into the cylinder by permitting partial expulsion of the charge during the early part of the compression stroke thereby limiting the maximum output of the engine under full throttle, first means for phase shifting the inlet cam to advance the closing and opening times by equal amounts so as to provide a first increase in maximum power output by increasing the valve overlap and increasing the trapped charge, and second means for varying the event duration so as to provide a further

increase in maximum power output by further advancing the closing times of the inlet valves to increase the intake charge without a corresponding advance in the opening times of the valves.

Preferably, each of the two means for increasing maximum engine power output are directly operated by the throttle regulating mechanism.

When the regulating mechanism is an accelerator pedal, the throttle will be opened fully after less that the full travel of the pedal and thereafter the two means are operated progressively to increase the power output while the engine remains under full throttle.

The invention will now be described further, by way of example, with reference to the accompanying drawings in which:

Figure 1 is a schematic plan view of the cylinder head of an engine in accordance with the invention,

Figure 2 is a section taken on the line II-II in Figure 1, and

Figure 3 is a graph of torque versus engine speed which clarifies the employed control strategy.

In Figure 1 a camshaft 10 for the exhaust valves of the engine is driven by the engine crankshaft, by way of a suitable transmission train, which may be a gear train, a chain or a toothed flexible belt. The phase of opening and closing of the exhaust valves is thus fixed in relation to the angle of the engine crankshaft.

A helical gear 12 is fixed on to the camshaft 10 and meshes with a helical gear 14 on a layshaft 16, which is

capable of being axially displaced relative to the cylinder head by means of an actuator 15. The layshaft 16 carries a second helical gear 18 which is coupled by way of a harmonic drive 20 to a split camshaft 22 for the inlet valves of the engine.

The split camshaft 22 is formed of four separate parts 22a to 22d which are capable of limited angular movement relative to one another. Each of the part 22a to 22d carries a respective cam and of the four parts, the two parts 22b and 22c nearer the harmonic drive 20 are hollow and the outer two parts 22a and 22d pass through the hollow parts. Each of the four parts 22a to 22d is driven directly from the harmonic drive 20.

The harmonic drive will be better understood from the section of Figure 2 and is itself based upon a variable valve timing drive described in copending patent application No. 8604249, to which reference should be made for a fuller understanding of the construction and operation of the harmonic drive. The harmonic drive 20 comprises a housing 40 which is pivotable about the axis of the layshaft 16 and includes two fixed idler gears 42 and 44. A ring gear 46 is captive between the two idler gears 42, 44 and the helical gear 18 on the layshaft 16 and thus rotates with the gear 18. The idler gears act in place of a bearing support for the ring gear 46. This is advantageous on account of the little space available for journalling the ring gear 46 but if space is not confined then a plain bearing may be used.

The ring gear 46 is formed with two slideways arranged at right angles to one another and each receiving a respective slider 48 of which only one is shown in the section of Figure 2. The sliders are each formed with two racks and each of the four racks of the two sliders is coupled through a gear sector 52 to a respective one of the four cams associated with the inlet valves.

If the housing 40 is positioned such that the axis of the inlet camshaft 22 coincides with the centre of the ring gear 46, then the sliders 48 will rotate with the ring gear without side to side movement in their slideways and the valve event is determined solely by the cam profile. On the other hand, if the housing is pivoted as represented by the arrow 56 about the axis of the layshaft 16 to force the ring gear 46 to rotate about an axis offset from that of the camshaft 22, then as the ring gear 46 rotates, the sliders 48 move from side to side and at the same time act through the rack and pinion couplings 50, 52 on the individual cams to accelerate and retard the phase of the cams in each cycle. The oscillation imposed on the rotation of the cams varies the valve event thereby simulating an alteration to the cam profile.

The mechanism described in the drawings is thus capable of altering the phase of the inlet valves relative to the exhaust valves without alteration of the valve event by axial displacement of the layshaft 16 alone. The mechanism is also capable of altering the valve event without affecting the mean phase relative to the exhaust valves by pivoting the housing 40 about the axis of the layshaft 16. These two controls being totally independent, the mechanism effectively permits total control over both the event duration and the phase.

As previously mentioned, VVT has hitherto been proposed to compensate for bottom end performance of an engine whose valve timing is designed for high speed performance. The described mechanism is however capable of implementing a different control strategy which will now be described in more detail.

The engine cam profile and base timing are designed to provide just sufficient performance to take the vehicle through the urban drive cycle and is optimized for idle

and low load operation. To this end, the base timing provides little valve overlap and the cam profile has a valve event which is extremely long, typically 300°, to result in the inlet valve closing after the start of the compression stroke to cause partial expulsion of the charge and thereby reduce the volumetric efficiency. The resulting torque curve for different engine speeds is represented in Figure 3 by the curve 60 for full open throttle and by the area beneath this curve for part throttle. The power output of the engine is low but fuel performance and engine smoothness are maximized.

To increase power output in response to depression of the accelerator pedal beyond the point where the butterfly throttle is fully open, the actuator 15 is brought into operation to move the layshaft 16 to advance the inlet valve event. This now increases the valve overlap and reduces the extent of late inlet valve closing by equal amounts, tending to increase the volumetric efficiency by preventing expulsion of the charge and to improve the valve overlap for high performance rather than high economy operation.

With this alteration of the phase, the torque output is progressively increased up to the curve 80 in Figure 3. In the area between the curves 60 and 80, the butterfly throttle is fully open and the phase is progressively advanced.

This still does not achieve the peak volumetric efficiency of the engine since some degree of charge expulsion through late inlet valve closing still occurs. However, phase shifting alone cannot be employed since the valve overlap cannot now be increased and it is necessary to advance inlet valve closing without an equal advance of the times of inlet valve opening. This is done by means of the harmonic drive 20 which simulates a cam profile of progressively reduced event.

The different curves for different effective opening angles are represent by the shaded area 85 with the peak torque of the engine being represented by the curve 90. In the area 85 between the two curves 80 and 90, phase shift by movement of the layshaft 16 is at a maximum and the eccentricity of the ring gear 46 relative to the axis of the camshaft 22 is progressively increased.

As torque demand is directly related to the position of the accelerator pedal, the throttle butterfly, the actuator 15 and the ring gear 46 can only be moved in direct response to the position of the accelerator and the need for a control mechanism is obviated. A servo mechanism may be required in view of the forces needed to move the layshaft and the ring gear 46.

It may be injurious to the harmonic drive for it to be engaged above a specific engine speed or at least the degree of offset possible without damage to the drive may depend upon engine speed. To prevent accidental damage, a governor may be used to limit the permissible offset of the ring gear as engine speed increases.

The advantage of the strategy of the engine of the invention is that the harmonic drive, which introduces the most frictional losses, is only effective under high performance operation when the accelerator pedal is heavily depressed at low speed and under these conditions fuel economy is not a serious consideration and is intentionally sacrificed for the sake of higher torque. It should however be mentioned that even under the maximum torque operation, the engine is making better use of the fuel than a comparable engine without variable valve timing and if desired, the improvement in bottom end torque may be usefully employed to permit lower gearing ratios to be adopted.

Reference is made to our copending British Patent Application No. 8705837 which contains the same disclosure as the present application but the claims of which are directed to the mechanical construction of the engine.

CLAIMS

1. An internal combustion engine which comprises a fixed profile inlet cam having a long event duration and phased under low load conditions to achieve a small exhaust overlap and a closing time sufficiently delayed to reduce the intake charge into the cylinder by permitting partial expulsion of the charge during the early part of the compression stroke thereby limiting the maximum output of the engine under full throttle, first means for phase shifting the inlet cam to advance the closing and opening times by equal amounts so as to provide a first increase in maximum power output by increasing the valve overlap and increasing the trapped charge, and second means for varying the event duration so as to provide a further increase in maximum power output by further advancing the closing times of the inlet valves to increase the intake charge without a corresponding advance in the opening times of the valves.

2. An engine as claimed in claim 1, wherein each of the two means for increasing maximum engine power output is directly operated by the throttle regulating mechanism.

3. An engine as claimed in claim 2, wherein the regulating mechanism is an accelerator pedal and wherein the throttle is opened fully after less that the full travel of the pedal and thereafter the two means are operated progressively to increase the power output while the engine remains under full throttle.

4. An engine as claimed in any preceding claim, wherein the inlet camshaft is coupled to the exhaust camshaft by way of a layshaft constituting said first means, the layshaft having at least one helical gear in mesh with a helical gear on one of the camshafts whereby

axial displacement of the layshaft causes a phase shift between the two camshafts.

5. An engine as claimed in claim 4, wherein two helical gears of opposite pitch are provided on the layshaft whereby to balance the reaction forces on the layshaft and to provide a greater phase shift for a given axial displacement.

6. An engine as claimed in claim 4, wherein one of the helical gears on the layshaft engages directly with a harmonic drive which constitutes said second means and enables a harmonic oscillation to be superimposed on the rotation of the inlet camshaft to vary the event duration.

7. An engine as claimed in claim 4, wherein the camshaft consists of four independently rotatable parts each carrying a respective cam and the harmonic drive comprises a ring gear retained within a housing which is itself pivotable about the axis of the layshaft, two mutually perpendicular slideways on the opposite faces of the gear, two sliders movable in the slideways and each having two opposed racks which engage gear sectors fast in rotation with the respective parts of the inlet camshaft.

8. An engine as claimed in claim 7, wherein the ring gear is retained within the housing by engagement of the ring gear with the layshaft gear and two idler gears mounted in the housing.

9. An engine adapted to operate substantially as herein described with reference to and as illustrated in Figure 3 of the accompanying drawings.

Published [illegible] at The Patent Office, State House, 66/71 High Holborn, London WC1R 4TP. Further copies may be obtained from The Patent Office.